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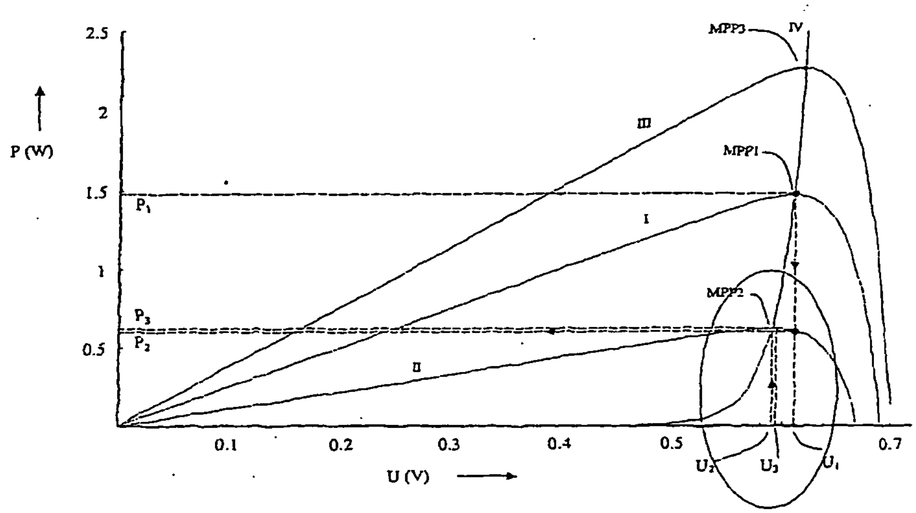
(54) Title: MAXIMUM POWERPOINT TRACKER



(57) Abstract: Maximum powerpoint tracker provided with memory means for storing information about the power produced by an energy source at a determined incoming power in this energy source depending as desired on the output voltage or the output current of this energy source, and with processor means for determining from this information the maximum power which can be produced by this energy source and the output voltage or output current required for this purpose, wherein the processor means are adapted to perform an algorithm according to which the maximum power which can be produced by an energy source and the output voltage or output current required for this purpose at a first incoming power in this energy source is determined from information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in this energy source.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

MAXIMUM POWERPOINT TRACKER

The invention relates to a maximum powerpoint tracker provided with memory means for storing information about the power produced by an energy source at a determined incoming power in this energy source depending as desired on the output voltage or the output current of this energy source, and with processor means for determining from this information the maximum power which can be produced by this energy source and the output voltage or output current required for this purpose.

Such a maximum powerpoint tracker, generally designated with the abbreviation MPP-tracker, is a per se known circuit which is applied to maximize the power produced by an energy source with varying power. Examples of such an energy source are photovoltaic systems and wind turbines.

The known MPP-tracker "searches" for the maximum power in the power curve of an energy source, and sends this information to a control circuit which applies a voltage over the output of the energy source (or draws off a current from the energy source) such that it produces a greater output current (or has a higher output voltage) as the power increases, and produces a smaller output current (or has a lower output voltage) as the power decreases. The power curve is defined in the foregoing as the progression of the power produced by the energy source as a function of the output voltage or the output current of this energy source.

In the known MPP-tracker a search algorithm for a so-called extreme value adjustment is applied in order to determine the maximum power which can be drawn off at a given incoming power in the source, for instance incident sunlight or intercepted wind energy. In an extreme value adjustment the output voltage or the

output current of the energy source is changed in stepwise manner (increased or decreased), and the power produced is compared to power produced before the change. If the last-measured power is greater than the previously measured power, the output voltage or the output current is changed in stepwise manner in the same direction (i.e. increased or decreased). If the last-measured power is smaller than the previously measured power, the output voltage or the output current is changed in stepwise manner in opposing direction (i.e. decreased or increased).

It is a drawback of the known MPP-tracker that when the above described search algorithm is applied it responds relatively slowly to acute changes in the incoming power in the energy source. Such acute changes occur for instance in a photovoltaic system when cloud suddenly develops or clears away, and can occur in wind turbines in the case of local variations in wind-force. A slow response of the stepwise search algorithm results in a relatively long period in which the energy source does not produce its optimal power, and therefore in costly energy losses.

It is an object of the invention to provide an MPP-tracker which responds quickly to acute changes in the incoming power in an energy source for which this MPP-tracker is applied.

This objective is realized with a maximum powerpoint tracker of the type specified in the preamble, wherein according to the invention the processor means are adapted to perform an algorithm according to which the maximum power which can be produced by an energy source and the output voltage or output current required for this purpose at a first incoming power in this energy source is determined from information stored in the memory means about the maximum power which can be produced and the output voltage or

output current required for this purpose at at least a second and a third incoming power in this energy source.

In an embodiment of a maximum powerpoint tracker according to the invention, the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in this energy source is given by a coefficient U' of an exponential function $P_{mpp}=U'e^{u_{mpp}}$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} required for this purpose (expressed in a dimensionless unit).

The exponential function $P_{mpp}=U'e^{u_{mpp}}$ is based on an ideal solar cell, i.e. a solar cell which, in a simplified model, is represented by a voltage source with a resistance-free diode connected in parallel. It has been found that an exponential function forms a good approximation of the stated relation.

In a practical advantageous embodiment the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in this energy source is given by the coefficients a_i of an n^{th} degree polynomial $P_{mpp}=\Sigma_{j=0}^{j=n} a_j u_{mpp}^j$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} required for this purpose (expressed in a dimensionless unit), wherein n is a whole number preferably equal to 2.

In a practical simple embodiment the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in this energy source comprises the parameters for describing a linear interdependence of the maximum power which can be produced and the output

voltage or output current required for this purpose at the incoming power.

A maximum powerpoint tracker according to the invention is preferably adapted to perform at predetermined time intervals a determination of the information about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in this energy source and to store this information in the memory means.

In an embodiment of an MPP-tracker according to the invention the algorithm comprises an iteration procedure.

In another embodiment the algorithm is followed after a predetermined instruction by a second algorithm for performing an extreme value adjustment, so that the maximum power which can be produced and the associated output voltage or output current can be determined with great accuracy. In a case where the first algorithm comprises an iteration procedure, the determined instruction comprises for instance of performing a predetermined number of iterations.

The invention will now be elucidated hereinbelow with reference to the drawings.

In the drawings

Fig. 1 is a diagram with three curves I-III which show the power P which can be produced by a solar cell as a function of the output voltage U, with a first curve IV which represents the maximum power P_{mpp} which can be produced by a solar cell as a function of the output voltage U_{mpp} at that maximum power which can be produced,

Fig. 2 shows a part of fig. 1 in enlarged view,

Fig. 3 shows a second curve IV' representing the maximum power P_{mpp} which can be produced by a solar cell as a function of the output voltage U_{mpp} at that maximum power which can be produced, and

Fig. 4 shows a third curve IV" representing the maximum power P_{mpp} which can be produced by a solar cell as a function of the output voltage U_{mpp} at that maximum power which can be produced.

Fig. 1 shows a diagram with three curves I-III representing the power P which can be produced by a solar cell as a function of the output voltage U at different incoming amounts of power, for instance as a result of different amounts of incident sunlight with varying cloud cover. The points MPP1, MPP2 and MPP3 in the respective curves I-III represent the maximum amounts of power which can be produced at the respective incoming amounts of power, and are connected by curve IV. The operation of the MPP-tracker according to the invention can be understood as follows. The power of a determined quantity of light incident in a solar cell corresponds for instance to a power which can be produced by this solar cell as according to curve I. The maximum power P1 which can be produced at an output voltage U1 is represented by the point MPP1 on curve I. In the case of a sudden fall in the quantity of incident sunlight, the power which can be produced corresponds to another curve, in the example curve II. At the original output voltage U1 a power P2 would be produced which is lower than the maximum power which can be produced in the conditions. According to the invention the MPP-tracker "searches" on the curve IV for the output voltage U2 corresponding to the power P2, then on curve II for the power P3 corresponding to the output voltage U2, on the curve IV for the output voltage U3 corresponding to the power P3, on curve II for the power P4 (not shown) corresponding to the output voltage U3 etc., until after a sufficient number of iterations there follows a search algorithm for an extreme value adjustment according to the prior art.

In practical situations, where the power curves of solar cells manufactured in accordance with a standard

process are known, the optimal power line IV can be predetermined and can be inputted into the memory of an MPP-tracker intended for that type of solar cells.

Fig. 2 shows an enlarged view of the part of fig. 1 enclosed by an ellipse.

Fig. 3 shows a curve IV' representing the maximum power P_{mpp} which can be produced by an ideal solar cell as a function of the output voltage U_{mpp} at that maximum power which can be produced. Curve IV' is calculated from the exponential function $P_{mpp}=U'e^{u_{mpp}}$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} required for this purpose (expressed in a dimensionless unit) for an ideal solar cell.

Fig. 4 shows a curve IV" representing the maximum power P_{mpp} which can be produced by a solar cell as a function of the output voltage U_{mpp} at that maximum power which can be produced, which curve IV" is calculated from a sixth degree polynomial $P_{mpp}=\Sigma_{j=0}^{j=6} a_j u_{mpp}^j$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} (expressed in a dimensionless unit).

An MPP-tracker according to the invention is particularly suitable for application in photovoltaic systems, in particular solar panels assembled from solar cells connected in series, where the shorter recovery time following a change in radiated power results in an increase in the produced power such that the extra investment cost of an MPP-tracker according to the invention is recouped in a relatively short time. The MPP-tracker according to the invention can however also be applied in other energy-generating systems, for instance wind turbines.

CLAIMS

1. Maximum powerpoint tracker provided with memory means for storing information about the power produced by an energy source at a determined incoming power in said energy source depending as desired on the output voltage or the output current of said energy source, and with processor means for determining from this information the maximum power which can be produced by said energy source and the output voltage or output current required for this purpose, **characterized in that** the processor means are adapted to perform an algorithm according to which the maximum power which can be produced by an energy source and the output voltage or output current required for this purpose at a first incoming power in said energy source is determined from information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in said energy source.

2. Maximum powerpoint tracker as claimed in claim 1, **characterized in that** the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in said energy source is given by a coefficient U' of an exponential function $P_{mpp}=U'e^{u_{mpp}}$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} required for this purpose.

3. Maximum powerpoint tracker as claimed in claim 1, **characterized in that** the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in said energy source is given by the coefficients a_i of an n^{th} degree polynomial

$P_{mpp}=\Sigma_{j=0}^{j=n} a_j u_{mpp}^j$ which describes the relation between the maximum power P_{mpp} which can be produced and the output voltage u_{mpp} required for this purpose, wherein n is a whole number.

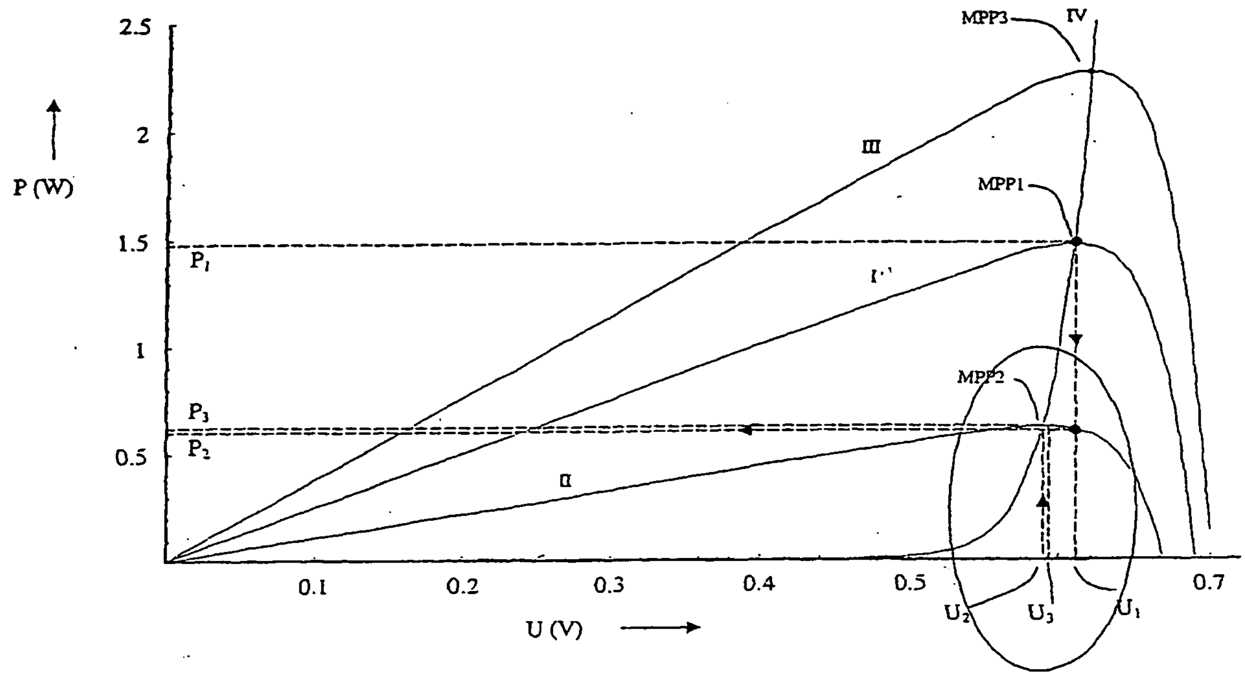
4. Maximum powerpoint tracker as claimed in claim 3, **characterized in that** n has the value 2.

5. Maximum powerpoint tracker as claimed in claim 1, **characterized in that** the information stored in the memory means about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in said energy source comprises the parameters for describing a linear interdependence of the maximum power which can be produced and the output voltage or output current required for this purpose at the incoming power.

6. Maximum powerpoint tracker as claimed in any of the claims 1-5, **characterized in that** it is adapted to perform at predetermined time intervals a determination of the information about the maximum power which can be produced and the output voltage or output current required for this purpose at at least a second and a third incoming power in said energy source, and to store this information in the memory means.

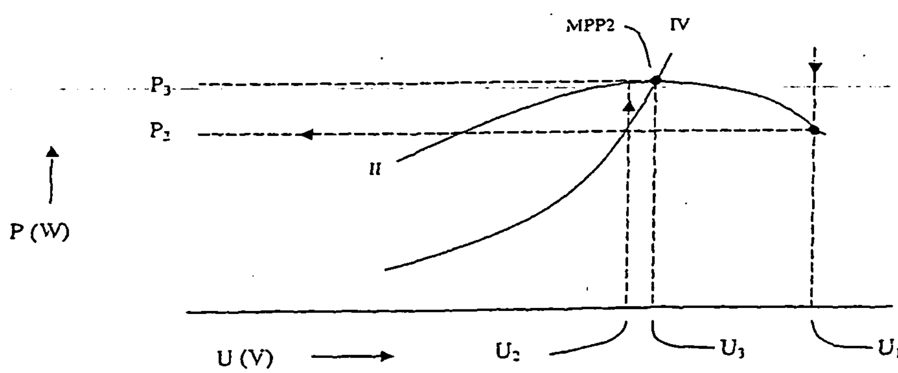
7. Maximum powerpoint tracker as claimed in any of the claims 1-6, **characterized in that** the algorithm comprises an iteration procedure.

8. Maximum powerpoint tracker as claimed in any of the claims 1-7, **characterized in that** the algorithm is followed after a predetermined number of iterations by a second algorithm for performing an extreme value adjustment.



2.5
2
1.5
1
0.5
P (W)
MPP3
IV
III
MPP1
P_1
MPP2
P_3
P_2
II
0.1
0.2
0.3
0.4
0.5
0.7
U (V)
U_2
U_3
U_1

Fig. 1



MPP2
IV
P_3
P_2
II
P (W)
U (V)
U_2
U_3
U_1

Fig. 2

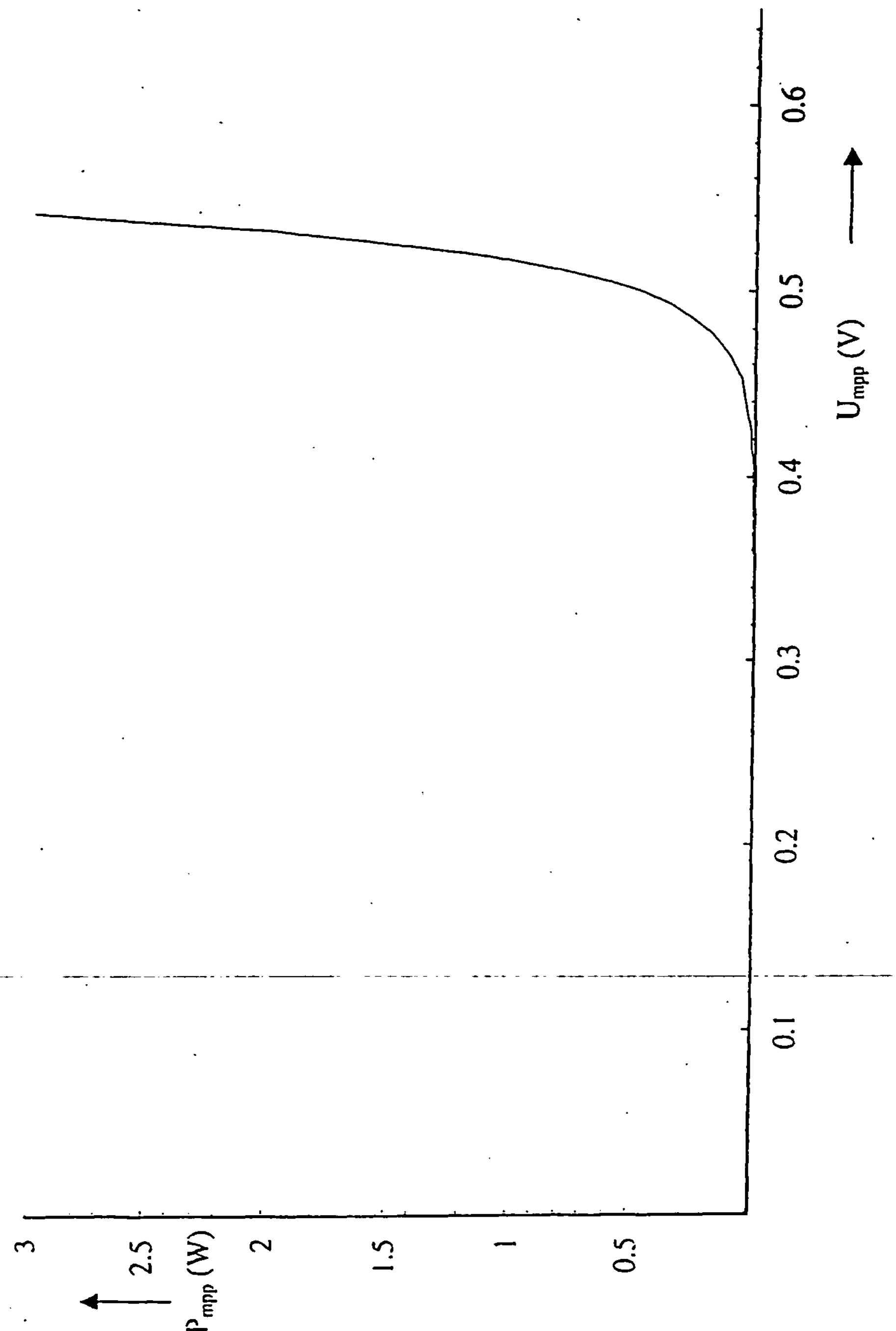


Fig. 3

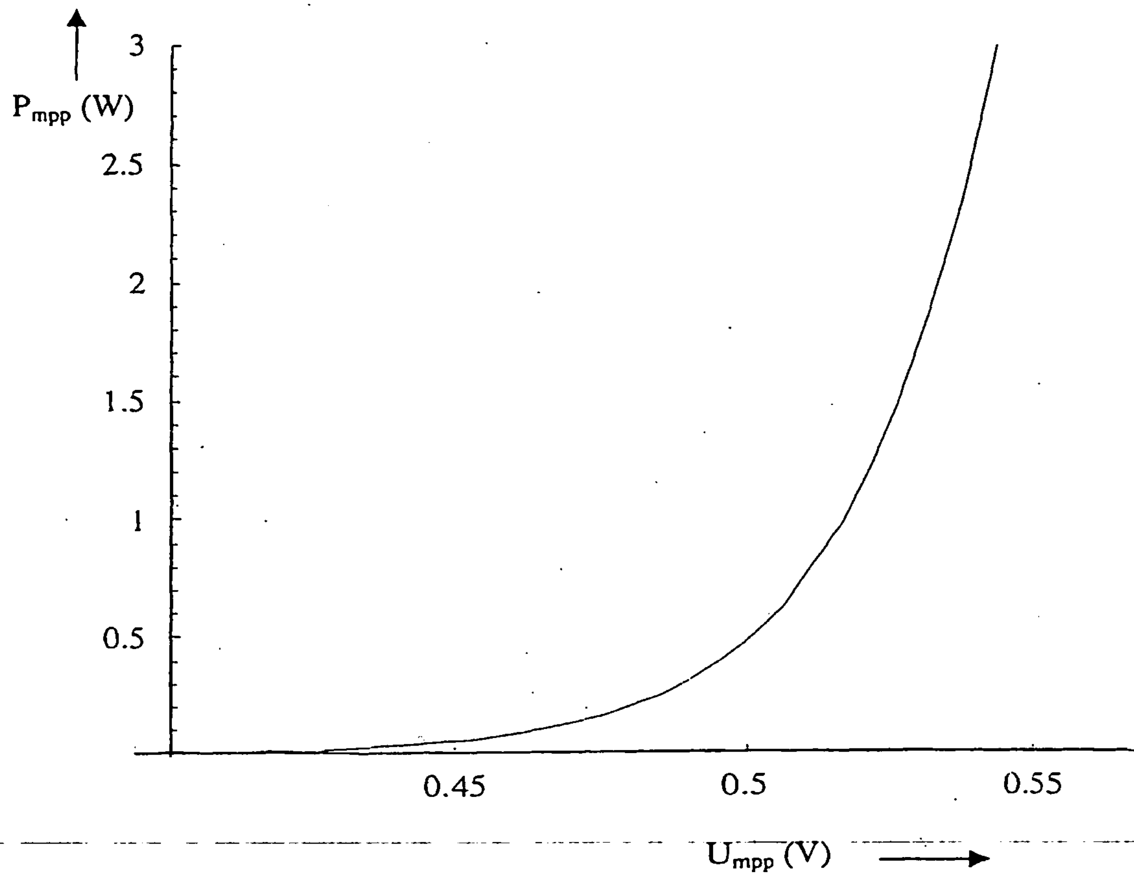


Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 02/00434

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G05F1/67 H02J7/35

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G05F H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 947 905 A (SANYO ELECTRIC CO) 6 October 1999 (1999-10-06)	1
A	the whole document	2-8

X	CHIHCHIANG HUA ET AL: "Comparative study of peak power tracking techniques for solar storage system" APPLIED POWER ELECTRONICS CONFERENCE AND EXPOSITION, 1998. APEC '98. CONFERENCE PROCEEDINGS 1998., THIRTEENTH ANNUAL ANAHEIM, CA, USA 15-19 FEB. 1998, NEW YORK, NY, USA,IEEE, US, 15 February 1998 (1998-02-15), pages 679-685, XP010263666 ISBN: 0-7803-4340-9	1
A	the whole document	2-8

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
14 October 2002	28/10/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schobert, D

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHIHCHIANG HUA ET AL: "DSP-based controller application in battery storage of photovoltaic system" INDUSTRIAL ELECTRONICS, CONTROL, AND INSTRUMENTATION, 1996., PROCEEDINGS OF THE 1996 IEEE IECON 22ND INTERNATIONAL CONFERENCE ON TAIPEI, TAIWAN 5-10 AUG. 1996, NEW YORK, NY, USA, IEEE, US, 5 August 1996 (1996-08-05), pages 1705-1710, XP010203239 ISBN: 0-7803-2775-6	1
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X	HUA C ET AL: "IMPLEMENTATION OF A DSP-CONTROLLED PHOTOVOLTAIC SYSTEM WITH PEAK POWER TRACKING" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, IEEE INC. NEW YORK, US, vol. 45, no. 1, 1 February 1998 (1998-02-01), pages 99-107, XP000735209 ISSN: 0278-0046	1
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A	US 5 604 430 A (DECKER DARWIN K ET AL) 18 February 1997 (1997-02-18) abstract -----	1-8

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
PCT/NL 02/00434

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